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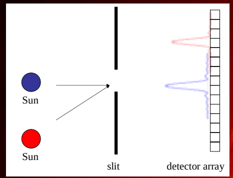
Diffractive Sun Sensor Analysis and Design

New Sun Sensor Concept

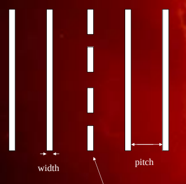
- A slit pattern is placed in front of a light sensitive array at a known gap
- Sunlight passing through slits casts a diffraction pattern on the array
- The shape and position of this pattern indicates the direction of the incident sunlight



Use Multiple Non-Interfering Slits for Redundant Readings

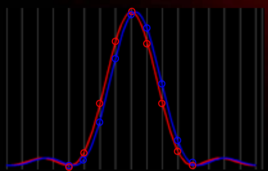
One slit would be sufficient to calculate the direction to the Sun. However, the diffraction pattern from a slit is small enough that we can place several slits adjacent to each other on the mask, and each will throw a separate, identical diffraction pattern on the detector. This allows us to take multiple measurements to increase the precision of the device.

In order to calculate the Sun vector, the detector needs to know which diffraction pattern came from which slit, so the slits need to be identified. This is accomplished by intentionally "dimming" the light from some slits in an unambiguous way.



Milli-pixel Resolution ⇨ Ultra-high Sensitivity

- Spread the diffraction pattern out over about 20 pixels, and fit the distribution to the analytical prediction
- Accuracies of fit of 1/100th of a pixel give 0.002° angular sensitivity for a 3 mm gap



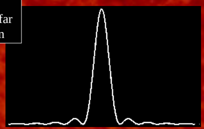
Abstract:

A sun sensor mounted on a spacecraft finds the direction to the Sun for orbital navigation. Current state-of-the-art sun sensor technology provides angular resolution to 0.1 degree at a cost of roughly $300,000 apiece. As many as 8 sensors are required per satellite. Using a new concept for a sun sensor, this project aims to improve resolution by a factor of up to 100 while simultaneously requiring fewer sensors to be deployed. At a basic level, the device consists of a slit pattern held in front of a light sensitive array detector. Sunlight passing through the slits creates a diffraction pattern on the array, and the position and shape of this pattern indicates the direction of incident sunlight. Design parameters include the precise arrangement of slits in two dimensions, the distance between the array and the slits, the size of the detector pixels, and the process by which the Sun vector is calculated from the detector data.

Diffraction Pattern Analysis, Current Progress

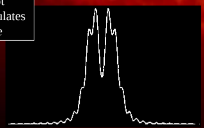
The patterns of light that will fall on the detector array are diffraction patterns. In order to back out the angular position of the Sun, we need to be able to predict these patterns. The gap between the slits and the detector array is typically on the order of millimeters, so the common far-field Fraunhofer diffraction approximation may not hold. The first part of this project was to model the diffraction pattern arising from any type of light coming from any angle onto a slit of any size, and being cast any distance to the detector.

First model: monochromatic light, far field diffraction pattern



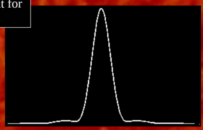
slit width: 20 micron
gap: 4 mm
incident light: 500 nm wavelength

Second model: does not assumer far-field; calculates pattern for any distance



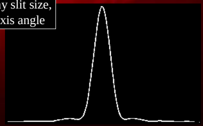
slit width: 25 micron
gap: 170 micron
incident light: 500 nm wavelength

Third model: account for polychromatic light



slit width: 20 micron
gap: 5 mm
incident light: visible white light

Current model: calculates diffraction pattern for any slit size, gap, spectrum, and off-axis angle



slit width: 20 micron
gap: 2 mm
incident light: visible white light
source off axis: 20 degrees

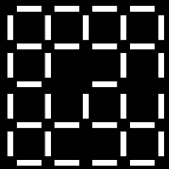
Design Tradeoffs

- There are several free design parameters involved with this concept for a Sun sensor. The current work on this project is aimed at exploring the design space (see table) and generating promising candidates to prototype
- Field of regard and angular resolution are two main figures of merit for candidate designs
- Typical fields of regard are between 30° and 100° with typical resolutions on the order of 10 arcseconds

Design Variable	Analysis, Commentary
Slit width	Wider slits cast a narrower diffraction pattern. This is good because it allows more closely packed slits, and therefore more readings per chip and greater sensitivity. However, wider slits let more light through. The Sun is extremely bright, and too much light will cause the detector to saturate, invalidating measurements. Manufacturing is another consideration – it may not be feasible to produce slits smaller than 3µm. Typical slit sizes are on the order of 10µm.
Slit pitch	Closer slit spacing gives more readings per detector for greater accuracy. However, the slits cannot be so closely spaced that their patterns overlap. Typical slit spacings are several hundred µm.
Gap	At a larger gap, a change in Sun angle will produce a larger movement of the diffraction pattern on the detector. Larger gaps give greater sensitivity. However, light from each slit spreads out more as the gap increases, so to keep patterns from overlapping, either the slits must get wider or spacing must increase. Both are undesirable. Typical gaps are around 1 mm.
Detector format	Detectors have different pixel sizes, number of pixels, saturation limits, and costs. For space flight, the detector must be radiation hardened.

Future Work

- All analysis and design so far has approximated the sun as a point source. This is not a good approximation because the solar disc subtends an angle in the sky of ~0.5 degree. The analysis is being adapted to model the Sun's full angular extent.
- The designs presented here are only sensitive in one axis. We are exploring bi-axially sensitive designs.



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